ACTIVITY REPORT

September 2002

Natural Gas & Oil Technology Partnership

bringing department of energy national laboratories capabilities to the petroleum industry

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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Upstream Environmental Technology Downstream Environmental Technology Natural Gas Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

Repair and testing of the Capacitive Discharge Downhole Source (CDDC), Regenerative Combustive Source (RCS) and the Tube Wave Suppressor (TWS) due to shipping damage started this reporting period. However, researchers were unable to complete these tasks due to conflicts with other projects with deadlines related to the fiscal year end.

Three of the four high voltage power supplies had potting compound cracks due to the tool being dropped in shipment. The cracks result in internal arcing which does not allow the capacitor banks to reach maximum charge. The first attempt at repair was unsuccessful.

Activities for repairing and re-assembly of the two seismic sources are to reconvene in the latter part of October. The high-pressure (deep well simulation) tests of the CDSS are also to occur in the same time frame. The modifications of the RCSS include DC power (compatible with the CDSS power supply) and increased power. Alternate power and/or telemetry co-deployment systems are being purchased in support of the project. November is the selected target window for resumption of tests.

Acoustic Telemetry (MWD)

(ABB, Electroacoustics Research Laboratory, Extreme, and SNL)

Project researchers are preparing the final documentation. The documentation includes a detailed description of the prototype tools as well as a discussion of the field test results.

Project researchers continue to support the commercial development of acoustic telemetry with industrial participants through the development of a special reflector sub and the loan of one of the prototype tools for an in-house trade show.

Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

Highlight:

- Researchers attempt to accelerate the sealant hardening time without affecting the pumping time.

Project researchers are focusing on accelerating the sealant hardening time under downhole conditions. Currently, the sealant sets very slowly downhole. Researchers initiated a methodical study to find the cause of slow hardening, and how to accelerate it.

Project researchers employed x-ray diffraction analyses to explore the mineralogy of the sealant. The only distinct peaks that could be observed were those of a small amount of unreacted magnesium oxide that is a component of the binder, and alumina from the ash. X-ray diffraction patterns of well-set sealant also exhibit these phases. However, the peaks of magnesium potassium phosphate hexahydrate that are prevalent in the well-set sealants were absent. Instead, a large hump was found at angles where peaks are normally dominant. This hump indicates the existence of a microcrystalline or amorphous phase. Researchers concluded that magnesium potassium phosphate hexahydrate was indeed formed, but probably this phase was amorphous or microcrystalline. Without formation of larger crystals, setting will not occur.

Currently, researchers are investigating various ways to promote faster crystallization of the amorphous or microcrystalline magnesium potassium phosphate hexahydrate. The methods include use of larger grain sizes of magnesium oxide, some of which will act as nuclei for crystallization, use of slightly less water to reduce a film of water between microcrystals, and use of accelerators to promote faster hardening.

Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring

(DeepLook, Phillips, and LANL)

Highlights:

- Researchers evaluated the improved mud cleaning system during a drilling demonstration.
- A revised procedure to cement a PVC casing was also evaluated.

A second microhole drilling demonstration at San Ysidro, NM was initiated through the second of two 2-1/2-in. steel conductor pipes that were previously installed. The coiled-tubing microdrill rig was rigged up to drill a 2-3/8in. hole. A low flow 1-11/16-in.-OD positive-displacement drilling motor and a 6-blade PDC, drilled to 458 ft or 360 ft in 4 hours (90 ft/hr) using fresh water with RD-60 polymer/flocculent to aid in solids removal. The mud pump performed well with discharge pressure of 1,500 psi at 30-gpm flow, which produced an average annular velocity of 160 ft/min above the BHA, and 260 ft/min across the BHA. Intermittent excessive cuttings across the shaker, and the occasional helical lock-up when in harder formations, indicated bore wall washout was occurring. Attempts to operate the low-flow drilling motor at less than 30 gpm resulted in excessive stalling and a great reduction in the penetration rate.

The microhole was drilled with a modified mud system. The improvements consisted of installing a higher capacity pump to increase the velocity through the hydro-cyclone mud cleaners, and building a polymer mixing/dispensing tank to facilitate the use of a low-molecular-weight flocculating polymer. The mud-system performance was improved significantly but the desired improvement in the mud pump reliability was not clearly evident. A 250-mesh shaker screen was subsequently installed on the mud cleaner in an attempt to further improve system performance. Inspection of the old 150-mesh screen upon removal revealed that a small tear allowed the flow of abrasive solids to the mud pump.

In order to complete the microhole, a revised cementing procedure was developed to prevent cement run away during the initial displacement. The 1.660-in. OD, schedule 40, flush joint, PVC casing was run to 540 ft in the second hole. A 3/8-in. orifice was installed at the bottom of the string to regulate annular cement velocity. Researchers mixed Portland cement slurry w/2% bentonite and 0.25% CFR-2 friction reducer, and 6.5 gal. water per sack, strained it through a 1-in. mesh screen below the mixing hopper, and pumped it down the PVC pipe. The orifice at the bottom of the string plugged after two sacks of slurry were displaced into the annulus.

A second microhole, temporarily abandoned in July, was reentered. After ten sacks of slurry were pumped, the surface pumping pressure increased suddenly and exceeded the capability of the Moyno grouter pump. The pressure increase was instantaneous, indicating another possible plug in the orifice at the bottom of the string. Sufficient cement was pumped to more than fill the casing and the calculated volume of the annulus with in-gauge hole to surface. It was decided to leave the casing in the hole because the string could not be re-used. Filling the annulus with cement completed the abandonment.

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

Highlights:

- Project researchers initiated an investigation of the sensitivity of post-perforation permeability for the full range of relevant parameters.
- Researchers are analyzing experimental data from a series of recent flow tests conducted on perforated liquid and gas saturated cores of Berea sandstone.

Recent enhancements to the computational model allow researchers to simulate the transient pressure surge that immediately follows perforation. This pressure surge results in removal of post-penetration debris and a cleanup of the damaged zone immediately adjacent to the perforation. Coupling this newly incorporated cleanup mechanism with the previously developed model of fines migration allows for a detailed investigation of the relative influences of rock and fluid properties and perforating conditions on post-perforation permeability.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL

Highlights:

- Researchers continue tensile testing of rope specimens.
- Initial work on insertion of reflective interfaces is successful.

Tensile testing of braided rope specimens with integrated optical fibers continued this reporting period. The ability of the fiber strain sensor to directly measure the applied strain in the rope is at issue in this testing phase. Complete results will be available in the next reporting period.

Initial work on creating reflective interfaces in the polymeric fibers was successful. The creation of these interfaces, which will allow strain gauge segments to be produced at desired lengths and at arbitrary intervals along the fibers embedded in mooring ropes, are essential for implementation of the optical time domain reflectometer OTDR strain measurement technique. The interfaces were produced using laser interferometry to form Bragg gratings in the polymeric fiber. The first gratings had insertion losses in the range of 1 to 5 dB. The efficiency of the gratings, i.e. ratio of backscattered light to total light lost at the interface, is approximately 50%. These initial results are very encouraging; however, the insertion loss ultimately should be less than 1 dB and the efficiency should be greater than 90% to achieve the performance objectives for a distributed strain sensor. Work will continue on the reflective interfaces in the next reporting period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Highlights:

- On September 24, an initial yard test consisting of injection and integrity verification of over 1,100 m began.
- On September 25, the remaining 200 m of fiber was successfully injected at about 18 km per minute (km/min).
- A pump test of about 4.5 hours continued while the fiber was monitored for integrity.

Project researchers began an initial yard test consisting of injection and integrity verification of over 1,100 m. Injection rates of approximately 300 ft per minute and 200 ft per minute were attempted. The optical fiber broke almost immediately at both of these injection rates, due to the initial feed and the inability of the reel of optical fiber to start turning. The injection was restarted again with the feed reel much closer and the feed off of the bottom of the reel instead of the top. A slower feed rate was achieved and the oscillations were minimized. However, when the feed slowed to a stop, the fiber broke again. Disassembly of the injector revealed that the inlet tube and toe outlet tube of the injector were completely clogged with a fiber material. The filter in the water pump had deteriorated and the fiber material found in the injector was filter particles.

A new filter was installed and injection was restarted at a rate of about 60 to 70 ft per minute. The rate gradually increased until control of the feed reel was lost and the fiber jumped off of the feed reel, wrapped around the shaft of the

reel mount and broke. The fiber that was injected was measured with an Optical Time Domain Reflectometer (OTDR) and researchers learned that 522 to 525 m were successfully injected.

The remaining 200 m of fiber were successfully injected at about 18 km per minute (km/min). The length of the coiled tubing used for the final test was 5631 ft, or about 1.85 km. Approximately 2.4 km of optical fiber was loaded into the injector and injection started at an average of 18 km/min. Control of the feed reel at this injection rate was exceptional, and at 1 hour and 39 minutes, 1.95 kilometers of fiber were successfully injected. A pump test of about 4.5 hours was continued while the fiber was monitored for integrity. The fiber survived the limited pump test.

The fiber injection and the pump test were successful, and future yard tests with a minimum of 16 hours of pump tests on the injected fiber are planned, dependent upon funding. The yard test will be followed by a field test under actual down-hole conditions, possibly during an acid injection, again dependent upon available funding.

Automatic Flaw Detection and Identification for Coiled Tubing (U of Tulsa, INEEL)

The design and fabrication of laboratory inspection equipment continues. Activities in this phase are as follows:

- A preliminary design of the coiled tubing inspection head was completed. Components and materials were ordered to fabricate the coiled tubing inspection head. Details and a fabrication drawing of a commercial eddy-current inspection head were obtained to use as guidance.
- Components to fabricate the laboratory inspection apparatus were ordered and received. A high-speed linear slide, stepper motor, and computer interfaces were also received.
- 10-ft lengths of coiled tubing samples were received from a manufacturer. Simulated defects will be placed in these tubes and used as the basis of the signal analysis tasks.
- An inspection head design was completed and fabrication began. All materials to complete this fabrication were received.
- A high-speed linear slide was ordered and received. The linear slide is capable of traversing the inspection head at a speed of 1 m/s. Initial software was completed to test the slide. Functionality will begin as soon as the inspection head fabrication is complete.
- INEEL personnel traveled to Calgary, Alberta, Canada to witness an eddy current inspection of a used coiled tubing string. Conversations with BJ Services, Canada and ICO, Shearer, Inc. personnel concerning the inspection equipment occurred. BJ Services agreed to tentatively provide access to a coiled tubing string for testing of INEEL-developed equipment and flaw identification and sizing computer algorithms. Detailed information about the ICO Shearer inspection was obtained through conversations with their field inspection supervisor. Digitized inspection was obtained. This provides information on the format of commercially generated inspection data. This information will be used to guide INEEL-generated data and acquisition equipment.
- Information on coiled tubing defect frequency was obtained through telephone conversations with consortium members.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

A multi-axial loading test setup was built for laboratory sand production and borehole breakout experiments. For the first year, the experiments will be conducted under dry conditions. This setup allows researchers to circulate a high-speed air current that simulates the transport and erosion effects of borehole fluids. The maximum principal stress and intermediate principal stress which are controlled by high-precision syringe pumps (ISCO) are applied parallel to a 1-in. thick slab of weakly cemented sand containing a single throughgoing borehole. The minimum principal stress applied to the faces of the slab is controlled manually using a pressure intensifier. The breakout of the borehole can be observed through a window built in the loading frame. Using this setup, project researchers will perform parametric studies of the grain-scale parameters of weakly cemented sand (intergranular cementation, porosity, angularity, etc.) and stress state on the behavior of borehole breakout and sanding. Researchers also nearly completed fabrication and assembly of a sonic frequency acoustic device for measuring the viscoelastic moduli of weakly cemented sand. This device will be used in the development of empirical relationships between small strain dynamic viscoelastic moduli in the sonic frequency range and the intergranular cohesion.

Development of Smart-Proppant Technology for Hydraulic Fracturing

(U of Tulsa, and INEEL)

The subcontracts to the University of Tulsa were completed. Industrial participants were contacted for information and additional efforts to engage additional industry participants are ongoing. The development of appropriate BioSep materials and "carry" materials appropriate for deployment are ongoing.

Oil and Gas Recovery Technology

Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Experimental work at the INEEL is complete and the final report is in preparation. At the request of U of Wyoming, submission of the final report is pushed back to October. As a result, the project is scheduled to end in October 2002.

Fluid Identification Acoustic Logging Tool

(BP Amoco, CGG, ChevronTexaco, Conoco, Landmark Graphics, Schlumberger, Shell, Smedvig Unocal, Ward Petroleum, Western Atlas, and LANL)

No work scheduled this reporting period.

Measuring Sucker Rod Pump Parameters Downhole (Harbison-Fischer, UT-Austin, and SNL)

Highlight:

- Project researchers acquired the equipment needed to upgrade the instrumented pump at UT-Austin.

A new hollow polished rod for the instrumented pump at UT-Austin was manufactured. Researchers will thread a cable through the polished rod to a specially fabricated load cell. Stuffing box friction can be measured directly with a load cell below and above the stuffing box.

Project researchers completed tests of pump performance with high viscosity oil, as well as tests using a pressure gauge mounted above the traveling valve, but ported to the compressing chamber. This new pressure transducer provides a direct measurement of pump fillage. Previous determinations of pump fillage relied on interoperation dynamics.

Formation Logging Tools for Microboreholes (DeepLook and LANL)

No work was scheduled for this reporting period.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling (Mobil, Schlumberger, UT-Austin, and SNL)

No report received.

Mechanisms of Oil Recovery and Validation of Corefloods (ChevronTexaco, Phillips, and LBNL)

Using the micro-mechanical distinct element method (DEM) code, project researchers created simplified 3D models of natural rock. By obtaining the digital images of packs of spherical particles at various resolutions, researchers were then able to assess the sensitivity of the pore network analyzing algorithm developed at UCSF.

Project researchers continued statistical analysis of thin sections of sandstones. Different correlation functions and other statistical tools were tested and benchmarked. Researchers learned that the main difficulties of this approach are the recreation of the connectivity of the pore space and mimicking the granular structure of the solid phase. Thus far, the most reasonable reproduction of the original image of a sandstone sample was obtained by a combination of two-point correlation and chord-length distribution functions. Substantial work was done to optimize the algorithms and reduce the processing time.

Researchers made good progress towards developing a pore network extraction code based on methods of mathematical morphology. The procedure was tested on simple structures and is yielding good results. The object-oriented code is being developed in C++. The anticipated end-product of this new code is a means to output a pore network file for modeling flow properties using code NetSimCPP.

Project researchers completed work on microscopic mechanisms that describe the drainage of three fluid phases, and implemented the results into a pore-network model.

Direct Simulation of Near-Wellbore Mechanics (ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continues on the refinement and application of the 2D code, and the implementation of the 3D code. In addition to the principal investigator (PI), contributing project staff includes graduate interns Dave Boutt (NM Tech) and Scott Johnson (MIT), and a new Sandia postdoctoral associate, Erik Strack.

The focus of work with the 2D code is on large-scale validation and appli-

cation studies. Validation studies conducted during this period include: 1) recovery of the Carman-Kozeny permeability-porosity relationship with direct numerical simulations of pore-scale flow through synthetic porous media; and 2) reproduction of the Terzaghi consolidation phenomenon initiated by consolidation-induced pressurization of pore fluids followed by seepage. Application studies are currently focused on the simulation of cavity formations in unconsolidated sands. After extending the code's boundary conditions to include specified fluid pressures at in-flow and out-flow boundaries, researchers are building an enlarged cavity formation model with approximately 10,000 particles and 1,000,000 fluid nodes. This application is the largest coupled simulation performed with this code to date. Researchers will be exploring parameters controlling cavity stability in the upcoming project period. Finally, in response to industry participants' request for additional documentation of the 2D code, researchers began work on a comprehensive help system to assist novice users in the application of the code.

In 3D, research into alternate, more realistic particle representations to the commonly used spherical discrete element continued. Researchers extended a recently published pseudo-ellipsoidal representation, which shows great promise as a computationally compact and physically realistic representation for natural particles like sands. The refined numerical algorithm for contact detection was implemented in a Matlab test program and showed an approximate five-fold speedup over the previously published scheme.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, Conoco, ExxonMobil, Halliburton, Kerr-McGee, Phillips, Shell, and SNL)

Highlight:

- The modeling effort was expanded to include three idealized deepwater GoM sub-salt near-salt reservoir settings.

The current work focus is on reservoir-scale finite element analyses. The goal of this work includes analysis of changes in vertical and horizontal principal stresses around salt bodies, changes in stresses during production, and analyses of displacement fields in the overburden, reservoir formations, and implications well casing integrity. The modeling effort was expanded to include three idealized deepwater GoM sub-salt near-salt reservoir settings, including a spherical salt body, a horizontal salt sheet, and a salt pillar with tongue. The analyses are being performed at three initial states of stress, including lithostatic, and two different ratios of horizontal to vertical stress. Elastic analyses are being performed, in addition to the more sophisticated analyses including the effects of transient and steady state salt creep.

Year 2 funding from all of the nine industry participants cleared DOE/SNL.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP, ChevronTexaco, Conoco, Halliburton, Marathon, OGCI, Phillips, Piezo Sona-Tool, Schlumberger, Shell, UC-Berkeley, LBNL, and LANL)

Highlight:

- Project researchers were invited to give a talk at "The Best of the 2002 D&P Forum."

On August 20-21, 2002, Peter Roberts from LANL attended a first-of-its-kind international conference, titled "Elastic Wave Effects on Fluids in Porous Media," at Gubkin State Oil and Gas University in Moscow, Russia. More than fifty researchers from China, Latvia, the Netherlands, Poland, the US, and Russia attended the conference. The meeting's purpose was to review ongoing research efforts to understand the phenomenon of seismic and acoustic interactions with fluids and gas in porous media, with a specific focus on enhanced oil recovery. Roberts (a co-principal investigator from the current NGOTP project) attended this conference as co-organizer, invited speaker and representative of US/DOE research efforts on this subject. The majority of the technical talks were given by Russian experts, who are acknowledged as pioneers in the field of seismic stimulation research. A major outcome of this meeting was to form

a seven-person international steering committee to implement plans for creating a research and informational exchange center at Gubkin University, with a possible branch center in the United States. Roberts was voted onto this committee by conference attendees.

On August 26-30, 2002, project principal investigators presented a talk titled "Seismic Stimulation of Oil Production: DOE Project Overview" at the SEG/SPE Development & Production Forum in Snowmass, Colorado. These annual forums feature lively discussions on topics of special interest to the SEG and SPE communities. The theme of this year's forum was: "Improved Prediction, Productivity and Profitability Using Geophysical Tools." The talk was very well received by the attendees and researchers were invited to present it again in Salt Lake City at the annual SEG meeting as part of a special session titled "The Best of the 2002 D&P Forum." Project researchers were also invited to submit a review article about this work to the SEG's monthly publication, *The Leading Edge*. These successes indicate a significant growth in the interest in seismic stimulation has occurred over the last several years.

High-Resolution Microseismic Monitoring of Reservoir Processes (ABB Offshore Systems, ChevronTexaco, Shell, and LANL)

Highlights:

- Researchers completed re-location work of five Cotton Valley hydraulic fracture treatments.
- Researchers computed source parameters and focal mechanisms for Cotton Valley data sets.
- A summary of the Cotton Valley re-analysis was presented at the SEG Development and Production Forum.

Project researchers completed re-picking the Cotton Valley data sets, and generated high-precision images from the new arrival-time data. Focal mechanism solutions were also determined using polarities and amplitude ratio data. In addition, researchers computed the source parameters using the new locations and radiation patterns determined from the focal mechanisms. These Cotton Valley results will be used as benchmarks to test and compare automated event classification and re-picking schemes.

Direct Quantification of Uncertainties Associated with Reservoir Performance (LANL)

Project researchers are working on a new NGOTP project for developing computational algorithms to parallelize and modify the existing code for single-phase fluid flow in heterogeneous reservoirs.

To obtain prediction uncertainties, the moment-equation-based approach requires solving the second moment-equations for all nodes of interest. In the current code for single-phase fluid simulation, these equations are solved sequentially. The computational efforts can be significantly reduced by recognizing that these equations are mutually independent and thus can be solved in parallel.

Meanwhile, work began on the Monte Carlo simulations. Researchers are comparing different random field generators in order to choose one that can reproduce better specified parameter statistics.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output, Phillips, and LANL)

Laboratory tests on a shake table were performed comparing various small sensors. These sensors include commercially available accelerometers and geophones, in addition to pre-commercial units and devices designed and built for this project. They were simultaneously excited with larger, conventional sensors and their spectra normalized in order to compare signal to noise ratios. Additionally, the smaller sensors were all deployed in a test well alongside a conventional 3-component geophone package. A final field comparison test is being prepared, after which the data will be analyzed.

Improved Prestack Kirchhoff Migration for Complex Structures

(Conoco, Cray/SGI, Golden Geophysical, Kerr-McGee, Shell, and LANL)

No report received.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, Conoco, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Highlight:

- Project researchers are preparing a proposal for AVO (amplitude vs. offset) waveform inversion research.

The petroleum industry widely uses analysis of seismic reflection amplitude vs. source-receiver offset distance to infer subsurface lithologic and/or pore-fluid properties. AVO assists in discovery of natural gas reservoirs, and subsequent characterization of reservoir material properties. However, current AVO theory and practice adopt numerous simplifying assumptions which limit the full potential of the method. Project researchers propose to simulate the exact seismic reflection response of a subsurface geologic bed of finite thickness (including primary P and S reflections from both bounding interfaces, all internal multiples, and all mode-conversions) with a reflectivity or wave number integration algorithm. A search method will then seek the particular set of layer parameters (such as compressional and shear wave speeds, mass density, attenuation factors, and anisotropic moduli) that reproduce the observed seismic data within a specified tolerance level.

Project researchers are modifying the present nonlinear full waveform elastic inversion algorithm to incorporate a priori constraint information into the iterative inversion procedure. Researchers designed the “hard constraints” to impose spatial uniformity on the recovered model parameters within selected subsurface units (such as within an AVO target geologic bed).

Work also continues on preparing two presentations for the upcoming annual meeting of the Society of Exploration Geophysicists (SEG). One presentation describes the development of a novel finite integro-difference numerical algorithm for simulating wave propagation within an anacoustic (i.e., attenuative and dispersive) fluid medium. This approach constitutes an alternative to the conventional “memory variable” technique for calculating synthetic seismic data in absorptive media. The other presentation involves computing several 3D elastic modeling examples for the SEG post-convention workshop “Advances and Limitations in Numerical Modeling of Wave Propagation in Challenging Structures.”

In addition, project researchers are preparing a proposal for AVO (amplitude vs. offset) waveform inversion research for presentation at the fall NGOTP Diagnostics and Imaging Technology forum.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro GeoServices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Unocal, Veritas DGC, Western Geophysical, Stanford, U of Houston, LANL, and LLNL)

Highlights:

- Parameters for a new, large 3D model are being defined.
- A new method for correcting migration velocities was developed.

Project researchers are working with several industry participants to define parameters and test the feasibility of performing very large acoustic and elastic 3D simulations through a new industry-defined subsalt geologic model. The model is approximately 18 x 28 km in horizontal extent and 10 km in depth. A frequency of 15 Hz is desired for the simulations. These numerical simulations will require up to 1 terabyte of internal memory on massively parallel computers.

Researchers developed a method to perform residual prestack migration of P-S data that can be applied after wave-equation prestack migration (common-azimuth or shot profile). Prestack residual migration is capable of correcting for both the misfocusing of the image and the lateral shift in conversion point caused by an inaccurate migration velocity.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

BP Amoco, ChevronTexaco, Exxon-Mobil, JNOC, Landmark, Phillips, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

Highlights:

- A paper describing the matching of tracer observations was submitted to the journal *SPE Formation Evaluation*.
- A paper describing an application to three-dimensional partitioning tracer observations was published in the *Journal of Water Resources Research.* The data were gathered at the Hill Air Force Base.

Preliminary extension of the production and seismic time-lapse inversion code to three dimensions began in August. Project researchers began to set up a 3D synthetic case to test the program. Researchers also continued the 2Dl testing of the inversion code. The tracer inversion part of the code was applied to a set of observations from a large multi-well multi-tracer Partitioning Interwell Tracer Test (PITT) in the McClesky sandstone, Ranger Field, Texas, to characterize both permeability and oil saturation distribution. During a typical PITT, a conservative and a partitioning tracer are injected into the reservoir. This approach is extremely efficient because it relies on analytic computation of the sensitivity of the tracer response to reservoir parameters such as permeability and saturation using a single streamline simulation.

Project researchers follow a two-step procedure whereby researchers first match the conservative tracer response to determine the permeability distribution and then match the partitioning tracer response to obtain oil saturation distribution in the reservoir. The entire history matching took less than six hours on a PC as opposed to several months typically required for a manual history matching.

Project researchers compared the results to a manual history match obtained using a finite-difference simulator. Both the manual history matching and the streamline-based inversion identified similar large-scale trends in permeability and saturation distribution. However, well-specific matches were significantly improved over those obtained through the manual history matching. The project's approach is much more efficient in terms of computation time and effort, and the results are less sensitive to personal bias compared to manual history matching. Researchers were able to match a set of tracer observations gathered at a producing oil field.

Researchers met with an industry participant. The discussion focused on the approach to matching the seismic time-lapse amplitude observations. Researchers compared the approach with a technique under development in-house and showed progress to date. Preparations are underway for the upcoming consortium meeting coinciding with the Fall SPE meeting.

Offshore Oil Field Characterization with EM Methods (SNL)

Building on the existing 3D electromagnetic (EM) modeling software developed at SNL, a matrix-free finite difference solution (Weiss, 2001) is now available for the marine magnetotelluric (MT) problem. A series of model studies were conducted which computed the synthetic MT response of the Gemini Salt Structure, Gulf of Mexico, whose spatial extent was inferred from 3D seismic data provided by Texaco. The synthetic results compare favorably with those published in 2000 by Hoversten et al. and validate use of the code for in-house testing of alternative modeling packages designed to address the issue of bathymetric effects on seafloor EM response. Results of the Gemini model study were presented at the recent 16th EM Induction Workshop, Santa Fe NM (Key et al., 2002). Additional results are to be presented at the upcoming annual meeting of the American Geophysical Union (Weiss et al., 2002).

To address the issue of bathymetric effects on seafloor MT response, a 2D finite element code was recently developed, also utilizing the matrix-free paradigm for enhanced computational efficiency. Numerical tests and checks are currently underway. The finite element code uses an unstructured mesh derived automatically from a constrained Delaunay triangulation (Shewchuk, 1997) of an initial pointset consisting only of the bathymetric profile and the corners of the computational domain.

Publications

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Innovative Wave-Equation Migration (Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, Conoco, Exxon-Mobil, Fairfield Industries, GX Technology, Petroleum GeoServices, Phillips, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

A project meeting was held on August 27 in the offices of Amerada-Hess, Houston, Texas. There were 37 participants from resource and service companies such as Amerada-Hess, BHP, Baker Atlas, Conoco, ExxonMobil, GXT, Kerr-McGee, Phillips, Shell, ChevronTexaco, and Unocal. Project researchers reported progress on limited aperture migration, high-resolution wave-equation migration, and common-angle wave-equation migration. Researchers solicited comments and suggestions from industry participants. They expressed great interest in the project, and provided valuable suggestions on the focuses of the project.

Testing and Validation of High-Resolution Fluid Imaging in Real Time (LBNL and SNL)

Work continued on modeling and system design of a seismic-electromagnetic imaging (EM) integrated tool for single-well imaging. Several critical issues are being addressed such as directionality, sensitivity, band width, and real-time processing capability. After evaluating the real-time processing difficulties, we postponed it in the work plan until the third year to address "show stopper" issues beforehand.

Modeling and initial field tests of the EM and seismic components indicate that the initial goals of the project can be met. The focus to date has been on determining minimum noise levels and band width to achieve the desired sensitivity. Work at LBNL focused on the design, fabrication, and testing of a high-frequency seismic source that generates P ad SH waves simultaneously and is smaller yet just as powerful as current sources.The source is now under going tests. At SNL seismic and EM modeling is being carried out to determine directional sensitivity, as well as sensitivity to several high-priority industry needs.

To evaluate the viability of integration, we successfully carried out noise tests with EM sensors integrated with the LBNL seismic system.

Autonomous Monitoring of Production (Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

The casing survey collected in May represented the first time-lapse field data (when compared with the initial baseline collected in October, 2001). While the measurement schedule was not optimal, researchers utilized independent information regarding the operational histories for the wells in the survey pattern to interpret the results. The key differences were a zone of decreased resistivity in the vicinity of the westernmost well in the pattern, and a generally diffuse decrease in resistivity across the center of the 9-spot well pattern, possibly diminishing toward the south. These changes can be interpreted in terms of injection histories in the field. The zone of greatest resistivity decrease occurs in the vicinity of the only well into which water had begun to be injected shortly after the baseline was obtained. (This well had been drilled a short time before the October baseline was obtained; prior to this, water had only been injected sporadically into the two nearby wells.) The largest, conductive anomaly is consistent with the introduction of relatively conductive water in the vicinity. The less pronounced anomaly is also consistent with the longer-term injection over the remaining area. No quantitative interpretation was attempted, due to the overall lower quality of these measurements, which were obtained with a random measurement schedule. Without additional independent data, these inferences cannot be confirmed.

A subsequent time-lapse casing survey was designed to optimize field acquisition while providing consistent data for comparison with the previous surveys collected at the field site. This time-lapse casing survey was repeated in September, 2002, with all wells connected to surface piping and electrical. This survey included the area to the north, which included wells into which CO_2 is being injected. This survey represents the first time-lapse during CO_2 stimulation. Data quality remained good, and the measurements were obtained with all wells connected and operating under normal conditions as well. The concatenated datasets show similar features. Differences between the datasets will be interpreted along with independent information regarding field operations.

In a parallel path, project researchers are developing options for remote operations. A complication is the remote nature of most oil fields, which precludes many wireless transmission systems. A satellite phone system was tested and found to be unsatisfactory. A more efficient option is being pursued.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, Conoco, LBNL)

No report received.

Realistic Velocity Anisotropic Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, Conoco, Kerr-McGee, Phillips, Shell, TomoSeis, LBNL)

Based on research by Grechka et al (1998) and Alkhalifah (1997), project researchers developed a velocity analysis code using non-hyperbolic moveout applied to midpoint gathers in VTI media. This code is used to access the accuracy of this method of estimating velocities and the effective anisotropy parameter, h. In order to more closely approximate the real world, researchers generated synthetic data using the new anisotropic FD elastic wave equation code rather than by ray-tracing, as in Grechka et al. (1998).

Two different approaches were considered for estimating V_{nmo} and h. A one step approach was considered where both V_{nmo} and h were estimated simultaneously by scanning V_{nmo} and h space during a semblance search. Researchers generated reflected arrivals by using a 4th order finite difference method to solve the anisotropic elastic wave equation.

The two-step method produced much better estimates of both V_{nmo} and h. The h estimates had greater error than the V_{nmo} estimates did. A range of h was considered with the same conclusions.

The next tests were conducted using the assumptions of VTI media to analyze Tilted Transverse Isotropic (TTI) media. The tests showed the increasing error induced in the estimated h by offset, as the travel path's distortion is proportional to the distance traveled in the TTI media.

Joint Geophysical Imaging

(ExxonMobil, UT-Austin, SNL, and LBNL)

Detailed knowledge of fluid properties in oil and gas reservoirs is critically important to increased production and extending the life of proven reserves. One technique that shows promise in characterizing fluids is the use of complementary datasets to better characterize the reservoir. Geophysical datasets (seismic, electromagnetic, gravity, etc.) on their own do not have sufficient resolving power to provide the level of information required on fluid properties, including water, oil, and gas saturation levels. However, preliminary studies (see below) indicate when combined with a petrophysical model of the reservoir, detailed fluid properties can be extracted. In a recently completed NGOTP project, SNL demonstrated the benefits of integrated reservoir monitoring using seismic and electromagnetic data. In addition, we contend that geological structure may be better constrained, which has important implications on drilling decisions. Past work on the combined use of seismic and electromagnetic (EM) has centered on an iterative interpreter driven process of using results from one technique to guide and constrain the interpretation of the other.

To date, the project has implemented a new 3D EM inversion code for marine measurement configurations. Inversion simulations for mapping variations in electrical resistivity for mapping hydrocarbons in the Snorre field, of the North Sea are now progressing. We are assuming knowledge of the reservoir boundaries defined through seismic studies. To image realistic 3D imaging volumes, the massively parallel computing resources available at SNL are being used. Discussions are under way with ExxonMobil to acquire a second reservoir test model. We have also started work with UT-Austin to link their AVO code to the 3D EM inversion scheme, which will result in a coupled inversion code for mapping fluid properties of the reservoir.